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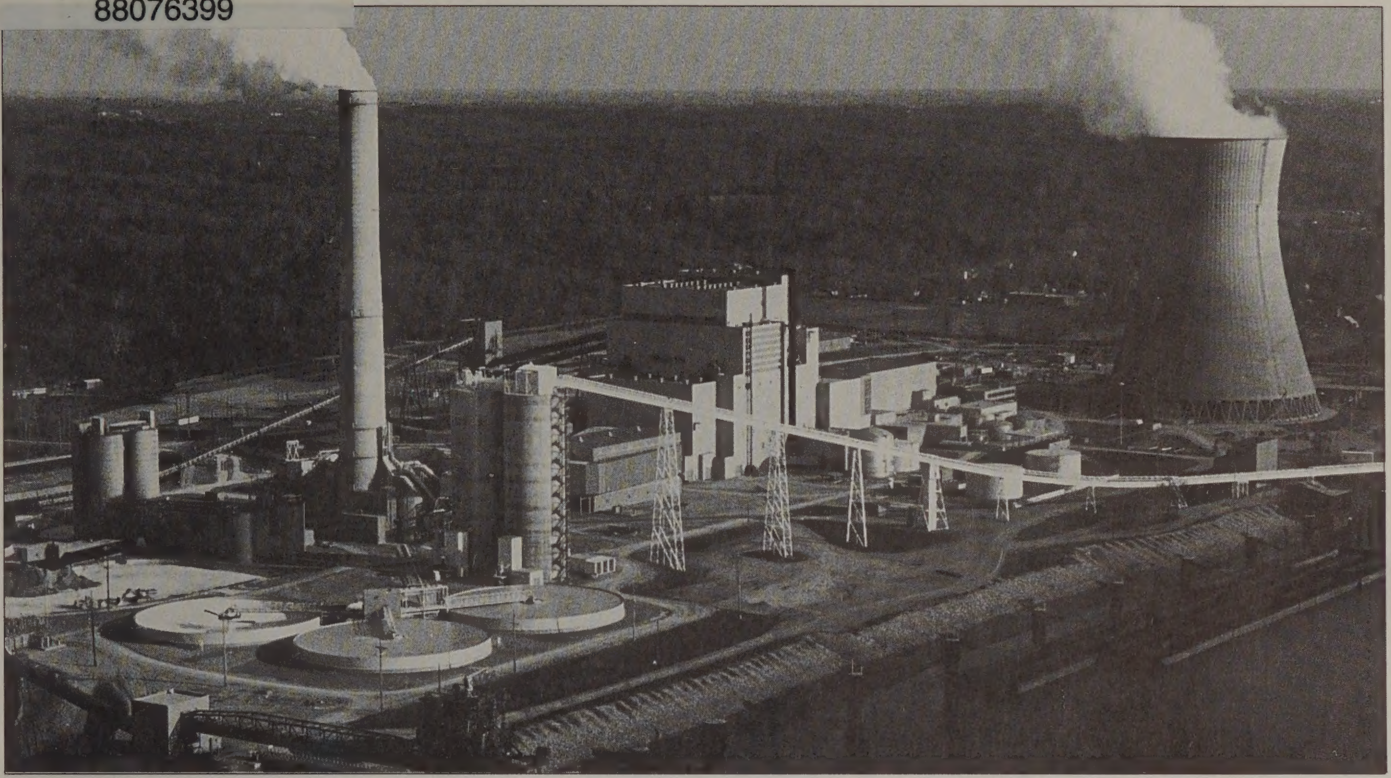

LIME

By M. Michael Miller

1990

U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

ANNUAL REPORT

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U.S.
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OF THE
INTERIOR

Manuel Lujan, Jr.
Secretary

BUREAU
OF
MINES

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Director

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COVER PHOTO:
The 1,300-megawatt coal-fired Zimmer generating station located on the Ohio River. The Zimmer station incorporates a magnesium-enhanced wet-lime process for the removal of sulfur dioxide. (Photo is courtesy of American Electric Power Service Corp. Columbus, OH.)

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LIME

By M. Michael Miller

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Lime is vital to the economic and enviromental well-being of the United States. It is a basic chemical that ranked fifth in total production in the United States in 1990. Its major uses are in steelmaking; pulp and paper manufacturing; construction; and the treatment of water, sewage, and smokestack emissions.

Total lime sold or used by domestic producers, including that from Puerto Rico, increased by about 300,000 short tons to 17.5 million tons in 1990. These products, valued at more than $905 million, included quicklime and hydrated lime for commercial sale or captive consumption. Commercial sales increased for the fourth straight year and were at record-high levels. Captive consumption decreased to the lowest level since the U.S. Bureau of Mines first collected accurate data on captive production in 1958.

TABLE 1

SALIENT LIME STATISTICS

(Thousand short tons unless otherwise specified)

	1986	1987	1988	1989	1990
United States:[1]					
Number of plants	116	116	115	115	113
Sold or used by producers:					
Quicklime	11,850	12,979	[r]14,066	[r]14,500	14,762
Hydrated lime	2,199	2,468	2,531	[r]2,249	2,313
Dead-burned dolomite	424	285	[r]455	[r]402	377
Total[2]	14,474	15,733	17,052	17,152	17,452
Value[3] thousands	$757,867	$786,125	$817,893	$852,113	$901,549
Average value per ton	$52.36	$49.96	$47.96	$49.68	$51.66
Lime sold	12,097	13,105	14,736	15,016	15,448
Lime used	2,377	2,628	2,317	2,135	2,004
Exports[4]	16	13	15	32	44
Imports for consumption[4]	201	178	210	218	173
Consumption, apparent[5]	14,658	15,898	17,248	17,337	17,581
World: Production	[r]136,234	[r]139,782	[r]147,872	[r]152,846	[e]150,151

[e]Estimated. [r]Revised.
[1]Excludes regenerated lime. Excludes Puerto Rico.
[2]Data may not add to totals shown because of independent rounding.
[3]Selling value, f.o.b. plant, excluding cost of containers.
[4]Bureau of the Census.
[5]Calculated by sold or used plus imports minus exports.

DOMESTIC DATA COVERAGE

Domestic production data for lime are developed by the U.S. Bureau of Mines from two separate voluntary surveys of U.S. operations. The survey used to prepare this report is the annual "Lime" survey. Of the 114 operations to which the annual survey request was sent, 112 responded, representing 98% of the total sold or used by producers shown in table 4. Production for the two nonrespondents was estimated using reported prior-year production figures.

BACKGROUND

Definitions and Specifications[1]

Lime is a manufactured product made by calcining limestone (calcium carbonate or a combination of calcium and magnesium carbonate) or other calcium carbonate materials at temperatures ranging from 1,800° F to 2,400° F. It is never found in a natural state. The calcination process drives off the carbon dioxide, forming calcium oxide (quicklime). The subsequent addition of water creates calcium hydroxide (hydrated or slaked lime). The term "lime" is a general term that includes the various chemical and physical forms of quicklime and hydrated lime. It may be high calcium, magnesian, or dolomitic. Quicklime is calcium oxide (CaO) with no water of crystallization. Hydrate is hydrated calcium oxide or calcium hydroxide [$Ca(OH)_2$] and contains 24% combined water. Dead-burned refractory dolomite is dolomite that has been calcined at 2,800° F to 3,150° F. Refractory dolomite is another name for dead-burned dolomite. All of these products are called lime.

Quicklime is commercially available by the carload, in bulk, or in paper bags, in the following standard sizes:

1. *Lump lime*—the product exceeds 2.5 inches in diameter. Although sizes can vary, the typical size is 5 by 8 inches. This largest size of quicklime is strictly a product of vertical kilns.
2. *Crushed or pebble lime*—the product

ranges in size from 0.25 inches to 2.25 inches, but the specific product size is more précise. This size has traditionally been a product of rotary kilns, but is now available from vertical kilns as either a primary product or as a result of crushing lump lime.

3. *Ground lime*—the product is generally ground from larger size material. A typical product size passes nearly 100% through a No. 8 sieve and 40% to 60% through a No. 100 sieve.

4. *Pulverized lime*—the product is the result of further grinding. A typical product size passes nearly 100% through a No. 20 sieve and 85% to 95% through a No. 100 sieve. This is usually a secondary product and is produced by intense grinding and classification.

5. *Pelletized lime*—almond-shaped pellets or briquets of uniform 1-inch size, molded from quicklime fines.

Hydrated lime is shipped in bulk tank trucks, railcars, and in 50-pound paper bags. As a result of the hydration process, it is of fine particle size. A typical product size passes 85% or more through a No. 200 sieve, and a few special applications may require a product passing 95% to 98% through a No. 325 sieve.

Because of the differences in limestones, a rigid standardization of lime material specifications is impossible. Few plants manufacture lime with exactly the same properties; as a result, lime specifications are by necessity quite general in their provisions. A typical analysis is shown in table 2.

TABLE 2

TYPICAL ANALYSES OF COMMERCIAL QUICKLIMES

Component	High-calcium quicklimes, range,[1] percent	Dolomitic quicklimes, range,[1] percent
CaO	93.25–98.00	55.50–57.50
MgO	.30– 2.50	37.60–40.80
SiO_2	.20– 1.50	.10– 1.50
Fe_2O_3	.10– .40	.05– .40
Al_2O_3	.10– .50	.05– .50
H_2O	.10– .90	.10– .90
Co_2	.40– 1.50	.40– 1.50

[1]The values given in this range do not necessarily represent minima and maxama percentages.

Source: "Chemical Lime Facts," National Lime Association.

Technology[2]

Lime manufacture involves three main processes: stone preparation, calcination, and hydration. Stone preparation involves quarrying or mining (including drilling, blasting, and conveying broken stone), crushing, and screening to provide the proper size kiln feed. Care is taken to avoid contamination with undesirable impurities, such as iron oxide, silica, and alumina. Although most lime manufacturers produce their own stone, some purchase the stone for kiln feed from commercial limestone producers.

Calcination is a simple chemical reaction. It is the addition of heat to limestone to cause thermal decomposition, in which the coproducts of CaO (quicklime) and CO_2 (carbon dioxide) are formed. This process is performed in a kiln, of which there are a wide variety of systems in use. The two basic kiln designs are rotary and vertical (or shaft). There are a few other miscellaneous designs, but the majority of commercial kilns are of rotary or vertical design.

A rotary kiln is a long cylindrical kiln with a refractory lining, inclined at a slight angle, rotated at a slow speed, and fired by fuel at the lower end. The calcareous raw material (kiln feed) is fed into the upper end and calcined at about 2,000° F during its travel through the kiln to form quicklime, which is discharged at the lower end. The calcination temperature depends on size and composition of kiln feed and the type of desired product. The carbon dioxide is driven off as a gas and normally exits the system with the stack gas.

Vertical kilns are short, wide, vertical cylinders lined with refractory materials. They are usually circular in cross section, typically with a diameter of 9 to 14 feet and a height of 50 to 70 feet. They are the most widely employed type in the world, especially in Europe. A vertical kiln is divided into four distinct zones where specific parts of the manufacturing process take place. They are, from top to bottom, (1) stone storage zone, (2) preheating zone, (3) calcining zone, and (4) cooling and discharge zone.

Examples of other kiln designs are the rotary hearth kiln and the fluosolids kiln. The rotary hearth design consists of a preheater, circular hearth, and cooler, all refractory lined. Stone is placed on the hearth and rotated through a heating chamber. In the fluosolids kiln, fine-sized stone is densely suspended by air and hot gases in the preheating and calcining zone of a vertical heated chamber. It can be operated at lower temperatures because of the fine stone size. The quicklime product is the most highly reactive of any commercial lime.

Byproducts and Coproducts

Most lime companies mine their own limestone or dolomite for kiln feed. Some companies also coproduce crushed and pulverized stone. If practical and markets exist, byproduct fines from the kiln feed preparation process and kiln dust from the calcination process are also marketed. Precipitated calcium carbonate is produced as a coproduct at three commercial lime plants by combining quicklime with byproduct carbon dioxide recovered from the kiln. Byproduct carbon dioxide is also recovered for use in the carbonation step of sugar refining.

Substitutes

Limestone is a low-cost substitute for lime for many uses such as agriculture, fluxing, and flue gas desulfurization (FGD). Limestone contains less reactive material, is slower to react, and may have other disadvantages compared to lime, depending on the use. Calcined gypsum is an alternative material in industrial plasters and mortars. Cement, lime kiln dust, and fly ash are potential resources as substitutes for some construction uses of lime.

Economic Factors

Prices.—Traditionally, lime has been a low-priced commodity. Its average value, as reported to the U.S. Bureau of Mines on an f.o.b. plant basis, ranged from $4 to $15 per ton from 1910 to 1970. It was only in the 1970's, when energy prices escalated, that lime prices showed a progressive and dramatic increase. This steady increase continued into the 1980's, although at a slower pace. In 1987, lime decreased in value for the first time since 1968. When comparing prices over the past 20 years, based on constant 1990 dollars, two trends become evident. From 1971 to 1980, prices increased steadily, finishing the period up 46%. From 1981 to 1990, prices decreased steadily, finishing the period down 21%.

Costs.—Production costs in lime manufacture can be divided, in descending

TABLE 3

TIME-PRICE RELATIONSHIPS FOR LIME[1]

Year	Average annual price, dollars per ton	
	Actual price[2]	Based on constant 1990 dollars
1971	15.78	46.74
1972	16.78	47.53
1973	17.42	46.28
1941	22.02	53.62
1975	27.46	60.89
1976	30.19	62.92
1977	33.50	65.46
1978	36.76	66.95
1979	41.26	69.03
1980	44.50	68.28
1981	47.01	65.76
1982	49.47	65.05
1983	51.10	64.67
1984	51.12	62.42
1985	51.69	61.29
1986	52.50	60.67
1987	50.11	56.13
1988	48.12	52.17
1989	49.83	51.88
1990	51.77	51.77

[1]Includes Puerto Rico.

[2]The average value of lime sold or used by producers f.o.b. plant excluding cost of containers.

order, into the following categories: energy (mainly fuel costs), kiln feed, dust collection, depreciation, direct labor, and miscellaneous. The ranking may differ from plant to plant, and most of the categories display a great range in costs from one plant to another. The difference in ranking and the range in costs are accounted for by such variables as distance from fuel sources; thermal efficiency of individual kilns; whether kiln feed is quarried, mined underground, or purchased; electrical energy rates; and age of the plant.[3]

Tariffs.—In the Harmonized Tariff Schedule of the United States, quicklime, slaked lime (hydrate), and hydraulic lime are listed under 2522.10, 2522.20, and 2522.30, respectively. Imports are free from countries with most-favored-nation (MFN) status and Canada. Non-MFN countries have tariffs of 0.2¢ per kilogram (about $2.20 per short ton) for quicklime, 0.3¢ per kilogram (about $3.31 per short ton) for slaked lime, and 0.2¢ per kilogram (about $2.20 per short ton) for hydraulic lime. Mexican imports of lime are assessed a countervailing duty of 1.21%. This applies to all Mexican lime producers included in the scope of a countervailing duty investigation completed in 1984 and a changed circumstances administrative review completed in 1989.

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Legislation and Government Programs

On November 15, 1990, the Clean Air Act Amendments of 1990 were enacted into law. "Title IV—Acid Deposition Control" was amended to include a market-based system of sulfur dioxide (SO_2) and nitrogen oxide emission reduction. The system is based on the allocation of emission allowances, which are calculated from emissions limits and baseline fuel consumption levels. An allowance allows the holder to emit 1 ton of SO_2 during or after the year in which the allowance was issued. Title IV of the law is directed at new and existing fossil fuel-fired electric generating stations containing one or more units that serve commercial generators of electricity. The domestic electric utility industry currently accounts for approximately 75% of annual SO_2 emissions. The goal is to reduce SO_2 emissions by 10 million tons from 1980 levels. To achieve this goal, emissions will be capped at 8.9 million tons by the year 2000.

In phase I, effective January 1, 1995, 110 existing electric utility plants with generating capacity in excess of 25 megawatts will be allocated SO_2 emission allowances. The allowances can be reassigned to other units within a utility's system, and they can be bought and sold between other allowance holders. Sulfur dioxide emissions cannot exceed the total of allocated and acquired allowances. Two-year extensions can be had for compliance with the allowance limitations if using a qualifying phase I technology achieving 90% SO_2 removal. Bonus allowances will be awarded for the installation of phase I technology; for achieving reductions before 1995; for achieving reductions through conservation and use of renewable energy; and to utilities in Illinois, Indiana, and Ohio.

In phase II, effective January 1, 2000, utility plants will receive emission allowances that are equal to 48% of the phase I allowance level. Four-year extensions can be had for utilizing clean coal technology. Bonus allowances will be awarded for achieving reductions through conservation or use of renewable energy, for operating in a State with a very low average emissions rate (as measured in 1985), for operating in 10 Midwestern States, and for additional special situations.[4]

The compliance options currently available to utility plants consist primarily of flue gas desulfurization (FGD) systems and fuel switching. FGD systems using either lime or limestone are used on more than 60 gigawatts of utility capacity. These systems have SO_2 removal efficiencies ranging from 50% to 95%. The high removal rates possible make FGD systems a cost-effective compliance option. This is despite their large size, relatively high capital costs, and byproduct waste disposal concerns.

Production

The term "lime," as used throughout this chapter, refers primarily to six chemicals produced by the calcination of high-purity calcitic or dolomitic limestone followed by hydration where necessary. They are (1) quicklime, calcium oxide (CaO); (2) hydrated lime, calcium hydroxide [$Ca(OH)_2$]; (3) dolomitic quicklime ($CaO \cdot MgO$); two types of dolomitic hydrate, (4) type N [$Ca(OH)_2 \cdot MgO$] and (5) type S [$Ca(OH)_2 \cdot Mg(OH)_2$]; and (6) dead-burned dolomite. Nondolomitic quicklime and hydrated lime are also called high-calcium lime. Lime can also be produced from a variety of calcareous materials such as aragonite, chalk, coral, marble, and shell. Lime is also regenerated; that is, produced as a byproduct, by paper mills, carbide plants, and water treatment plants; however, regenerated lime is beyond the scope of this report.

Total U.S. lime production from limestone, including that of Puerto Rico, was essentially unchanged. Commercial lime sold by producers increased by 434,000 tons from the previous year. Captive lime used by producers decreased by 131,000 tons or about 6% compared with the previous year.

In 1990, 70 companies produced lime. Leading producing companies, in descending order, were Dravo Lime Co. with two plants in Kentucky and one

TABLE 4

LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

State	1989					1990				
	Plants	Hydrated (thousand short tons)	Quicklime (thousand short tons)	Total[2] (thousand short tons)	Value (thousands)	Plants	Hydrated (thousand short tons)	Quicklime (thousand short tons)	Total[2] (thousand short tons)	Value (thousands)
Alabama	5	162	1,319	1,481	$70,361	4	154	1,372	1,526	$70,816
Arizona	3	W	W	W	W	3	W	W	W	W
Arkansas, Louisiana, Oklahoma	3	71	214	286	15,548	3	48	205	254	15,143
California	11	W	W	395	24,503	10	51	295	345	19,425
Colorado, Nevada, Wyoming	9	W	W	357	24,136	9	W	W	464	29,968
Oregon and Washington	4	W	W	393	26,348	4	W	W	406	23,046
Idaho	3	W	W	W	W	3	—	W	W	W
Illinois, Indiana, Missouri	8	458	3,196	3,654	168,979	8	530	3,174	3,704	173,559
Iowa, Nebraska, South Dakota	4	W	W	W	W	5	W	W	264	14,014
Kentucky, Tennessee, West Virginia	5	117	1,529	1,624	89,859	5	129	1,867	1,996	109,685
Massachusetts	2	W	W	W	W	2	W	W	W	W
Michigan	8	W	W	621	32,479	8	W	W	622	30,898
Minnesota and Montana	7	W	W	W	W	7	—	W	W	W
North Dakota	3	85	22	107	5,439	3	—	82	82	4,623
Ohio	9	W	W	1,888	94,157	9	W	W	1,884	92,817
Pennsylvania	10	300	1,360	1,660	92,139	10	345	1,280	1,626	92,557
Puerto Rico	1	26	—	26	3,800	1	29	—	29	3,483
Texas	8	367	937	1,304	60,829	8	314	1,024	1,337	76,181
Utah	4	W	W	373	17,974	3	W	W	354	18,878
Virginia	5	170	650	821	38,353	5	174	672	846	39,784
Wisconsin	4	120	317	437	18,129	4	119	342	461	24,608
Other[3]	([4])	611	5,146	1,750	72,880	([4])	448	4,825	1,279	65,547
Total[2]	116	2,487	14,690	17,178	855,913	114	2,341	15,140	17,481	905,032

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1] Excludes regenerated lime. Includes Puerto Rico.
[2] Data may not add to totals shown because of independent rounding.
[3] Includes data indicated by the symbol W.
[4] Included with data for each individual State.

TABLE 5

LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES,[1] BY SIZE OF PLANT

Size of plant	1989			1990		
	Plants	Quantity (thousand short tons	Percent of total	Plants	Quantity (thousand short tons)	Percent of total
Less than 10,000 tons	12	74	([2])	15	96	([2])
10,000 to 25,000 tons	19	318	2	18	317	2
25,000 to 50,000 tons	15	585	3	13	472	3
50,000 to 100,000 tons	21	1,496	9	16	1,168	7
100,000 to 200,000 tons	20	2,883	17	21	2,990	17
200,000 to 400,000 tons	21	5,844	34	23	6,298	36
More than 400,000 tons	8	5,979	35	8	6,140	35
Total[3]	116	17,178	100	114	17,481	100

[1] Excludes regenerated lime. Includes Puerto Rico.
[2] Less than 1/2 unit.
[3] Data may not add to totals shown because of independent rounding.

plant in Alabama; Mississippi Lime Co. in Missouri; Marblehead Lime Co. with two plants in Illinois and one each in Indiana and Michigan; Chemstar Inc. with two plants each in Arizona, California, and Nevada and one in Utah; Martin Marietta Corp. in Ohio; Allied Lime Co. with two plants in Alabama; Continental Lime Inc. with one plant each in Montana, Nevada, Utah, and Washington; APG Lime Co. with one plant each in Texas and Virginia; Chemical Lime Southwest with two plants in Texas; and LTV Steel Co. in Ohio. These 10 companies operated 26 plants and accounted for 57% of total lime production.

Domestic lime plant capacity is based on 365 days minus the average number of days for maintenance times the average 24-hour capacity of quicklime production, including quicklime converted to hydrated lime, and reported in short tons per year. Specific plant capacity data were available for 72% of commercial lime plants. Based on the data available, the commercial lime industry operated at 79% of capacity in 1990.

The industry announced a number of plant expansions and plans for new plant construction. Dravo Lime Co. began installation of a 800-ton-per-day preheater rotary kiln of Kennedy Van Saun design at its plant in Saginaw, AL. It was scheduled to go on-line in late March 1991. It will replace a 200-ton-per-day rotary, which will be placed in inactive status. Cheney Lime and Cement Co. began installation of a preheater rotary kiln of Kennedy Van Saun design at its plant in Shelby County, AL. It was scheduled to go on-line in the first quarter of 1991. Continental Lime Inc. began installation of a second kiln at its plant at Townsend, MT. The kiln was a used Allis Chalmers with a preheater of Continental design. Chemstar Inc. worked on zoning and permitting approvals for two new plants planned for Soda Springs, ID, and Cosgrave, NV. The plans for Soda Springs called for installation of a 600-ton-per-day Mertz vertical shaft kiln to go on-line the second quarter of 1992. Owing to zoning problems, Chemstar had to relocate its planned Winnemucca operation to Cosgrave, NV, about 6 miles northeast of the original site. The plant is expected to go on-line in the third quarter of 1992. Pfizer Inc.'s Specialty Minerals Group began a $13 million expansion at its facility in Adams, MA. The facility contains a crushed stone operation, lime plant, and precipitated calcium carbonate plant. The plans called for construction of a new office and laboratory building, renovation of an existing building, replacement of a 30,000-gallon lime slurry tank, and removal of several existing structures deemed inadequate for current needs. Additional annual expenditures are planned as part of a 10-year program to continue upgrading the facility, address environmental concerns, meet market projections, and maintain profitability.

Consumption and Uses

Lime was consumed in every State. The breakdown of consumption by major end uses was as follows: 66% for chemical and industrial uses, 24% for environmental uses, 8% for construction uses, and 2% for refractory dolomite. Captive lime was used mainly in sugar refining and in the production of steel in basic oxygen furnaces.

In steel refining, quicklime was used as a flux to remove impurities such as phosphorus, silica, and sulfur. Dolomitic lime

TABLE 6

DESTINATION OF SHIPMENTS OF LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

(Thousand short tons)

State	1989			1990		
	Quicklime	Hydrated lime	Total[2]	Quicklime	Hydrated lim	Total[2]
Alabama	483	47	529	589	38	627
Alaska	3	1	3	3	—	3
Arizona	257	70	326	254	59	312
Arkansas	183	31	214	170	27	197
California	479	127	606	521	120	640
Colorado	61	11	72	80	15	95
Connecticut	18	10	27	15	6	21
Delaware	12	4	16	14	2	17
District of Columbia	15	26	41	17	38	55
Florida	392	18	410	369	19	388
Georgia	314	81	395	238	70	308
Idaho	137	2	139	124	2	126
Illinois	575	144	719	639	183	822
Indiana	1,527	30	1,557	1,514	31	1,545
Iowa	70	22	92	79	29	107
Kansas	72	24	96	73	18	92
Kentucky	482	27	510	502	45	547

See footnotes at end of table.

TABLE 6—Continued

DESTINATION OF SHIPMENTS OF LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

(Thousand short tons)

State	1989 Quicklime	1989 Hydrated lime	1989 Total[2]	1990 Quicklime	1990 Hydrated lim	1990 Total[2]
Louisiana	272	98	370	325	105	431
Maine	(3)	1	1	—	—	—
Maryland	328	19	347	135	19	154
Massachusetts	148	12	160	145	9	154
Michigan	1,138	40	1,178	1,043	41	1,085
Minnesota	157	145	301	246	16	262
Mississippi	175	6	182	199	6	205
Missouri	183	55	237	196	67	263
Montana	132	13	145	206	13	218
Nebraska	66	76	142	61	13	74
Nevada	212	37	249	269	57	327
New Hampshire	—	1	1	—	—	—
New Jersey	101	22	123	106	24	130
New Mexico	187	33	220	166	21	187
New York	71	41	112	73	42	115
North Carolina	191	36	228	201	43	244
North Dakota	123	88	211	187	4	192
Ohio	1,369	139	1,508	1,453	147	1,600
Oklahoma	104	6	111	121	14	134
Oregon	115	25	141	104	33	136
Pennsylvania	1,826	233	2,059	1,900	265	2,165
Rhode Island	2	2	4	7	1	8
South Carolina	218	23	241	191	25	216
South Dakota	24	2	26	45	2	47
Tennessee	183	55	238	214	61	275
Texas	947	369	1,316	1,010	311	1,321
Utah	224	18	242	147	9	157
Vermont	—	1	1	—	—	—
Virginia	151	40	191	150	89	239
Washington	250	21	271	304	22	327
West Virginia	471	51	522	454	61	515
Wisconsin	112	47	159	128	47	175
Wyoming	68	19	87	95	22	116
Total[2]	14,628	2,449	17,076	15,082	2,290	17,376
Exports:						
Canada	35	13	48	39	17	56
Other countries[4]	28	26	54	17	29	46
Total	63	39	102	56	46	102
Grand total[2]	14,690	2,487	17,178	15,140	2,341	17,481

[1]Excludes regenerated lime.
[2]Data may not add to totals shown because of independent rounding.
[3]Less than 1/2 unit.
[4]Includes U.S. possessions.

was often substituted for a fraction of the high-calcium lime to extend refractory life. Dead-burned dolomite, also called refractory lime, was used to line the bottom of open-hearth steel furnaces to extend the life of the brick lining. Dead-burned dolomite was a component in tar-bonded refractory brick used in basic oxygen furnaces. Lime consumption for raw steel production remained essentially unchanged at 5.1 million tons and accounted for 29% of all lime consumed in the United States.

In nonferrous metallurgy, lime was used in the beneficiation of copper ores to neutralize the acidic effects of pyrite and other iron sulfides and maintain the proper pH in the flotation process. It was used to process alumina and magnesia, to extract uranium from gold slimes, to control pH and reduce cyanide loss in gold and silver leaching operations, and in the recovery of nickel by precipitation.

Lime was used in the softening and clarification of municipal potable water. In sewage treatment, lime was used to control pH in the sludge digester, which removes dissolved and suspended solids that contain phosphates and nitrogen compounds. It also aided clarification and killing of bacteria. Lime was used to neutralize acid mine and industrial discharges. In FGD systems serving utility and industrial plants, lime was used to react with sulfur oxides in the flue gas. Lime was used to stabilize sludges from sewage and desulfurization plants before disposal.

The paper industry used lime as a causticizing agent and for bleaching paper pulp to the desired degree of whiteness. Lime was also used in the clarification and color removal of paper mill wastes and to make precipitated calcium carbonate, a specialty pigment used in premium-quality coated and uncoated papers.

The chemical industry used lime in the manufacture of alkalies. Quicklime was combined with coke to produce calcium carbide, which was used to make acetylene and calcium cyanide. Lime was used to make calcium hypochlorite, citric acid, petrochemicals, and other chemicals.

In sugar refining, milk of lime, a suspension of hydrated lime in water, was used to raise the pH of the product stream, precipitating colloidal impurities. The lime itself was then removed by reaction with carbon dioxide to precipitate calcium carbonate. The carbon dioxide was obtained as a byproduct of lime production.

Dolomitic quicklime was used as a flux in the manufacture of glass. Quicklime was used to make calcium silicate building products such as sand-lime brick; hydrated lime was used to produce silica refractory brick.

In construction, lime was used for soil stabilization to upgrade clay soils into satisfactory base and subbase materials. Common applications included the construction of roads, airfields, building foundations, earthen dams, and parking areas. Hydrated lime was used with fly ash to make a base material; in asphalt mixes to act as an antistripping agent; and in plaster, stucco, and mortar to improve durability. Other applications of lime included agricultural uses, leather tanning, plastics manufacture, and pigments.

Prices

The average value of lime sold or used by producers, as reported to the U.S. Bureau of Mines on an f.o.b. plant basis, increased to $51.77 per short ton. Average values were $50.53 per ton for chemical and industrial lime, $58.70 for construction lime, $59.44 for lime used in agriculture, and $71.61 for refractory dolomite.

The average value of quicklime sold increased to $49.55 per ton. Average values per ton were $49.13 for chemical lime, $45.17 for construction lime, $57.10 for lime used in agriculture, and $67.60 for refractory dead-burned dolomite.

The average value of hydrated lime sold decreased to $60.88 per ton. Average values were $58.21 for chemical lime, $67.54 for lime used in construction, and $60.37 for lime used in agriculture.

Foreign Trade

Exports of lime increased by 37% to 44,287 tons. Imports of lime decreased by about 20% to 173,197 tons. Most U.S. trade was with Canada and Mexico, which together accounted for 99% of the U.S. imports and exports of lime. Canada was the major trading partner, receiving 80% of U.S. exports and shipping 87% of U.S. imports.

World Review

Denmark.—The largest lime producer in Denmark is Faxe Kalk, a 51% subsidiary of Aalborg Portland Holding A/S. Faxe Kalk and its subsidiaries produced an assortment of calcium carbonate derived products. Limestone was quarried near the town of Fakse and transported a short distance to the lime plant operation at Stubberup. Quicklime was produced from two rotary kilns, with some further processing into pulverized lime and hydrate. Hydrated lime was also produced at Vejle. Annual lime production by Faxe Kalk averages between 125,000 to 145,000 tons.[5]

Germany, Federal Republic of.—With the reunification of the two Germanies, the German Democratic Republic ceased to exist and became simply the Eastern states of the Federal Republic of Germany. Reunification and the resulting economic turmoil in the Eastern states had a large negative impact on lime production and lime markets in the Eastern states. Harzer Kalk-Werke GmbH was the largest lime producer in the Eastern states. It operated the following six limestone and lime facilities: Werk Rbeland, Werk Kaltes Tal, Werk Hornberg, Werk Bad Ksen, Werk Oberrohn, and Werk Schraplau. These operations supplied quicklime and hydrate for use by industries such as chemicals, steel, pulp, sugar refining, metallurgy, and agriculture. Production was down in 1990, primarily owing to the uncertainties facing the chemical industry of the former German Democratic Republic.[6]

Mexico.—There are about 130 lime plants in Mexico. The Fideocomiso de Minerales No-Metálicos Méxicanos, the Government agency that oversees the nonmetallic mining sector, classifies only 15 of Mexico's lime plants as "modern." These 15 plants produce about 50% of Mexico's annual production. Most lime producers are small and face three major problems: lack of quality control, low-level technology and antiquated equipment, and lack of adequate financing. Mexico's annual lime production ranges between 5 to 7 million tons. The two largest markets are the construction industry and the steel industry, which consume about 80% and 8%, respectively.

New Zealand.—Lime was produced on both the North and South Islands. There are only a relatively small number of "calcined lime" producers in New Zealand, where pulverized agricultural lime is also termed lime. Quicklime and hydrate were produced by McDonalds Lime Ltd. at

FIGURE 1

TRENDS IN MAJOR USES OF LIME

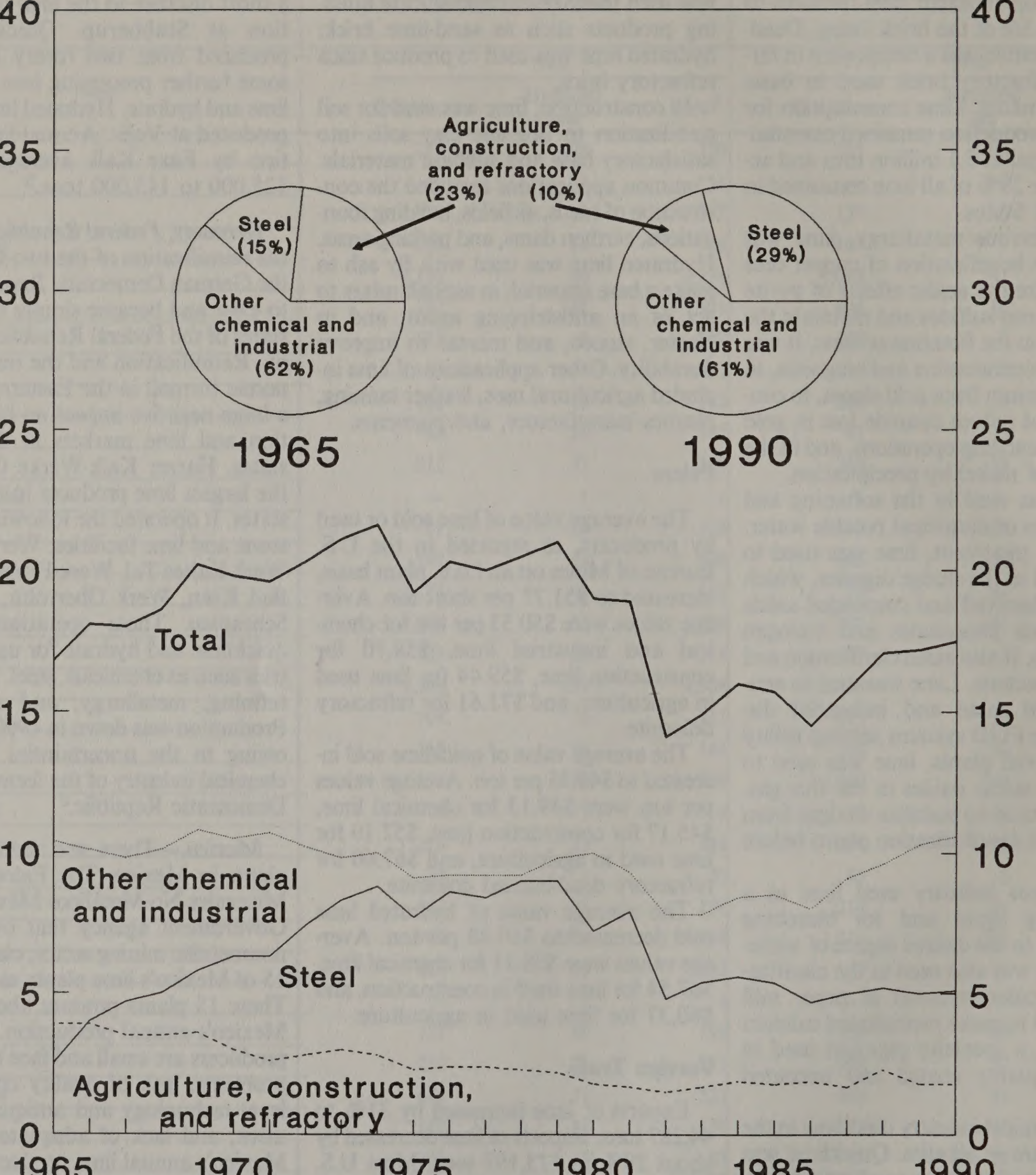

TABLE 7

LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE[1]

(Thousand short tons and thousand dollars)

Use	1989[r]				1990			
	Sold	Used	Total[2]	Value	Sold	Used	Total[2]	Value
Agriculture	56	—	56	3,077	49	—	49	2,898
Chemical and industrial:								
Alkalies	W	W	164	8,452	W	W	106	5,170
Aluminum and bauxite	169	—	169	8,383	155	—	155	8,122
Copper ore concentration	W	W	419	18,821	W	W	373	17,540
Food products, animal or human	28	—	28	1,534	21	—	21	1,171
Glass	130	—	130	6,418	99	—	99	5,022
Magnesia from seawater or brine	W	W	646	32,214	W	W	653	31,987
Oil well drilling	W	—	W	474	12	—	12	693
Oil and grease	18	—	18	889	W	W	19	1,283
Ore concentration, other	W	—	W	W	331	—	331	15,940
Paper and pulp	W	W	1,178	56,997	W	W	1,265	64,901
Precipitated calcium carbonate	W	W	W	W	W	W	254	11,718
Steel, BOF	W	W	4,051	187,567	W	W	4,034	193,254
Steel, electric	W	W	1,021	48,654	W	W	974	50,698
Steel, open-hearth	64	—	64	2,877	122	—	122	5,856
Sugar refining	40	642	682	34,214	30	627	657	35,596
Tanning	W	W	55	3,765	26	—	26	1,548
Other[3]	9,567	822	2,855	144,148	8,919	1,178	2,419	131,599
Total[2]	10,016	1,464	11,480	555,407	9,716	1,805	11,521	582,100
Construction:								
Soil stabilization	667	—	668	33,999	672	—	672	36,188
Finishing lime	207	—	207	22,372	160	—	160	14,708
Mason's lime	W	W	111	8,320	W	W	254	17,932
Other[4]	444	—	342	16,667	500	—	295	12,217
Total[2]	W	W	1,327	81,358	W	W	1,381	81,046
Environmental:								
Acid water, mine or plant	251	—	251	11,332	285	—	285	16,120
Sewage treatment	455	—	455	21,365	467	—	467	22,014
Flue gas sulfur removal	1,485	—	1,485	70,792	1,673	—	1,673	89,694
Water purification	1,030	—	1,030	49,134	1,072	—	1,072	50,271
Other[5]	665	26	691	34,549	647	10	657	33,900
Total[2]	3,886	26	3,912	187,172	4,143	10	4,154	211,999
Refractory lime (dead-burned dolomite)	W	W	402	28,899	W	W	377	26,988
Grand total[2]	15,042	2,135	17,178	855,913	15,476	2,004	17,481	905,032

[r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Excludes regenerated lime. Includes Puerto Rico.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes briquetting, brokers, calcium carbide, chrome, citric acid, commercial hydrators, desiccants, environmental uses (1989), explosives, ferroalloys, fiberglass, glue, insecticides, ladle desulfurizing, magnesium metal, manganese, metallurgy, pelletizing, pharmaceuticals, petrochemicals, precipitated calcium carbonate (1989), rubber, silica brick, soap, wire drawing, and uses indicated by symbol W in "Chemical and industrial" lime only.
[4]Includes asphalt antistripping.
[5]Includes industrial solid waste treatment, industrial wastewater treatment, scrubber sludge solidification, and other environmental uses.

TABLE 8
U.S. EXPORTS OF LIME

	Quantity (short tons)	Value[1] (thousands)
1987	12,644	$2,971
1988	14,908	3,113
1989	32,241	3,893
1990	44,287	4,755

[1]Customs value.

Source: Bureau of the Census.

Otorohanga and Te Kuiti on the North Island. McDonalds operated two coal-fired rotary kilns at Otorohanga and a gas-fired Mertz vertical kiln at Te Kuiti. Its major market was the steel industry, but it also supplied lime for sugar refining, soil stabilization, pulp manufacture, and water treatment. Taylors Lime Co. Ltd. operated on the South Island. In 1990, Taylors relocated its lime plant from Oamaru to Makareo and installed a new rotary kiln. The main objective in relocating the plant was to supply lime to the Macraes Flat gold-mining operation. Both McDonalds and Taylors are subsidiaries of Milburn New Zealand Ltd.[7]

Current Research

Researchers at the Illinois State Geological Survey Minerals Engineering Laboratory have developed a high-surface-area (HSA) hydrated lime for use in dry-sorbent FGD systems. The HSA hydrate is very reactive because it has a smaller particle diameter and crystallite size and greater surface area and porosity than commercial hydrates. The HSA hydrate was tested at the Environmental Protection Agency's (EPA) furnace sorbent injector reactor at Research Triangle Park, NC; Consolidation Coal's Coolside pilot unit at Library, PA; and Research-Cottrell's boiler economizer furnace at Irvine, CA. The tests determined SO_2 removal rates under conditions similar to burning high-sulfur coal. The tests were very favorable, and under most conditions demonstrated removal rates up to 70% higher than those of commercial hydrates.

Dry-sorbent injection systems are considered more cost effective for retrofitting smaller coal-fired powerplants of 150 megawatts or less. Such systems are smaller, easier to install and operate, and cost less than larger wet scrubber systems. The HSA hydrate could provide an effective sorbent for such systems that could significantly boost their SO_2 removal rates.[8]

In 1987, EPA accidentally discovered that quicklime had apparently destroyed polychlorinated biphenyls (PCB's) when applied to PCB-containing sludges for stabilization purposes. In an effort to explain this phenomenon, EPA's Risk Reduction Engineering Laboratory in Cincinnati, OH, funded a project with RMC Environmental & Analytical Laboratory of West Plains, MO, to conduct controlled experiments on PCB-contaminated soils. The unpublished results verified the field observations and showed that the addition of quicklime apparently destroys PCB's within about 96 hours. The end products of the chemical reaction were calcium chloride, water, and carbon dioxide. The reaction occurs at high temperature and pH levels and apparently requires a metal catalyst. The latter is probably supplied by the small amounts of magnesium, iron, or aluminum oxides normally found in high-calcium quicklimes.[9]

EPA researchers and non-EPA scientists recommended additional studies be conducted to confirm RMC's results and to collect additional data to determine whether PCB destruction or some other phenomena is occurring. The additional studies will be conducted in-house by EPA. If the results confirm PCB destruction with quicklime treatment, additional studies will be needed to determine in-field application methods, economics, reaction optimization, appropriate wastes to be treated, and to evaluate potential reaction byproducts.

OUTLOOK

Lime has dozens of end uses in the chemical, industrial, and construction industries. Steelmaking is still the largest single end use for lime, although the total consumption by tonnage and percentage of total lime production has decreased. During the past 20 years, lime consumed for steelmaking averaged 39% of total consumption. In 1990, consumption was essentially unchanged from that of the previous year at about 5.1 million tons or 29% of total consumption. The current level reflects a trend of the decreasing consumption by the steel

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF LIME

	Hydrated lime		Other lime		Total	
	Quantity (short tons)	Value[1] (thousands)	Quantity (short tons)	Value[1] (thousands)	Quantity (short tons)	Value[1] (thousands)
1987	39,734	$3,021	138,171	$7,558	177,905	$10,579
1988	54,419	4,031	155,497	8,541	209,916	12,572
1989	36,952	2,219	180,704	9,749	217,656	11,968
1990	29,920	2,147	143,277	8,245	173,197	10,392

[1]Customs value.

Source: Bureau of the Census.

TABLE 10

QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED DOLOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989	1990[e]
Algeria[e]	45	45	45	45	45
Australia[e]	1,210	1,210	1,210	[r]1,650	1,650
Austria	1,405	1,519	1,703	[r]1,788	1,700
Belgium	1,971	1,944	2,086	[e]2,100	1,980
Botswana	([3])	([3])	([3])	([3])	([3,4])
Brazil	5,411	5,842	[r]6,063	[r]6,316	6,280
Bulgaria	1,799	1,409	1,570	[r]1,581	1,540
Burundi	([3])	([3])	([3])	([3])	([3])
Canada	2,472	2,458	2,776	2,812	2,760
Chile[e]	[r]990	[r]1,100	[r]1,320	[r]1,430	1,430
China[e]	9,900	12,100	14,300	17,600	18,700
Colombia[e]	1,430	1,430	1,430	1,430	1,430
Costa Rica[e]	11	11	11	[r]25	22
Cuba	192	204	197	[e]200	200
Cyprus	8	8	8	8	8
Chechoslovakia	3,670	3,569	[r]3,650	[r]3,688	3,690
Denmark (sales)	147	132	148	[r,e]149	140
Dominican Republic[e]	37	40	40	39	39
Egypt[e]	105	105	105	105	105
Ethiopia	[r]6	[r]6	[r]4	[e]2	2
Fiji Islands	3	—	—	[r,e]2	—
Finland (sales)	[r]289	[e]300	224	[e]234	220
France	3,200	[e]3,300	3,405	[e]3,400	3,300
Germany, Federal Republic of:					
Eastern states	3,908	3,724	3,835	[e]3,750	3,300
Western states	7,139	6,736	[r]7,497	[r]7,753	7,940
Guatemala	41	88	79	[r]87	88
Hungary	916	916	938	[r]968	940
India[e]	660	770	830	[r]870	880
Iran[e]	700	700	700	700	700
Ireland	97	85	107	[r]123	110
Israel[e]	[r]143	[r]143	[r,4]143	[r]143	143
Italy[5]	3,969	4,292	[e]4,300	[e]4,300	4,240
Jamaica	101	99	88	[r,e]100	100
Japan (quicklime only)	7,404	7,435	8,516	[r]9,354	9,400
Jordan	5	4	[r]3	[r]3	3
Kenya	14	29	[e]28	[r]35	35
Korea, Republic of[e]	220	220	250	250	250
Kuwait	63	69	[e]72	[e]72	55
Lebanon[e]	11	11	11	11	11
Libya[e]	290	290	290	290	290
Malawi	3	3	[e]3	[e]3	3
Malta[e]	6	6	6	6	6
Martinique[e]	6	6	6	6	6
Mauritius[e]	8	8	8	8	8

See footnotes at end of table.

TABLE 10—Continued

QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED DOLOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1986	1987	1988	1989	1990[e]
Mexico	[r]6,662	6,889	6,614	[e]6,610	6,610
Mongolia[e]	[r]118	[r]134	[r]105	[r]100	100
Mozambique[e]	11	[r]6	[r]6	[r]6	6
Nepal	1	1	23	[r]45	50
New Zealand[e]	175	175	165	110	110
Nicaragua[e]	4	4	4	4	15
Norway[e]	110	110	110	110	110
Paraguay	97	102	94	114	116
Peru[e]	40	[4]14	14	14	14
Philippines	42	[e]20	4	[e]5	6
Poland	[r]4,528	[r]4,701	[r]4,883	[r]4,873	4,850
Portugal[e]	220	220	220	220	220
Romania[e]	4,100	4,000	3,900	3,600	3,530
Saudi Arabia[e]	13	13	13	13	13
South Africa, Republic of (sales)	2,143	1,744	2,112	2,138	[4]2,018
Spain[e]	1,300	1,300	1,300	1,380	1,320
Sweden	723	650	740	[e]740	720
Switzerland	39	44	[e]46	[e]44	44
Taiwan	[e]120	116	117	[e]110	110
Tanzania[e]	3	3	3	3	3
Tunisia[e]	720	720	720	720	720
Turkey[e]	1,200	1,200	1,600	[r]1,500	1,800
Uganda[e]	1	1	1	1	1
U.S.S.R.	33,204	33,203	[r]33,705	[r]33,486	30,860
United Arab Emirates[e]	50	50	50	50	50
United Kingdom[e]	2,750	3,100	3,100	3,100	2,870
United States including Puerto Rico (sold or used by producers)	14,498	15,758	17,077	17,178	[4]17,481
Uruguay	11	14	11	[r]13	13
Venezuela[e]	2	2	2	2	2
Yugoslavia	[r]2,927	2,754	[r]2,754	[r]2,658	2,200
Zaire	150	109	[r]111	110	110
Zambia	268	259	263	[r]353	330
Total	[r]136,234	[r]139,782	[r]147,872	[r]152,846	150,151

[e]Estimated. [r]Revised.
[1]Table includes data available through June 10, 1991.
[2]Lime is produced in many other countries besides those listed. Argentina, Iraq, Pakistan, and Syria are among the more important countries for which official data are not available.
[3]Less than 1/2 unit.
[4]Reported figure.
[5]Includes hydraulic lime.

industry. This trend is a result of the decreasing consumption of fluxing agents; thus, less lime is consumed per ton of steel.

The outlook for steel production in the U.S. is uncertain. Labor contracts will expire at major steel producers in 1991 and 1992 and Voluntary Restraint Agreements with foreign producers will expire in 1992. These uncertainties make forecasting U.S. steel production extremely difficult. One econometric model, based on the actual production from 1982 through 1989, assumes production will decrease from 1991 through 1994 and be followed by a strong recovery in 1995 and 1996. Steel production in 1991 is expected to decrease by 5% to 10% compared with that of 1990. Based on this forecast and the decreasing trend in flux consumption, lime consumption for steelmaking could

easily drop to 4.5 to 4.8 million tons per year by the early 1990's. This translates to a loss in consumption of several hundred thousand tons per year, most of which would be in commercial sales.

Other sectors of the lime market are more difficult to analyze. No other single end use consumes more than 10% of total consumption, although environmental uses when grouped together account for approximately 24%. FGD consumption has the greatest growth potential, having increased steadily since the U.S. Bureau of Mines began collecting consumption data for it in the early 1970's. With passage of the Clean Air Act Amendments of 1990, consumption of lime or FGD use is expected to grow dramatically during the 1990's.

New environmental legislation, a resurgence in environmental awareness and concern by the public, and expanded cleanup of hazardous waste sites may have an impact on environmental markets. Lime should be ideally situated to take advantage of a new emphasis on environmental cleanup. It is an important and economical component in the treatment of air, water, and solid wastes.

Other markets that have growth potential are in construction, precipitated calcium carbonate manufacture, gold mining, and caustic soda manufacture by the lime-soda process using trona (natural sodium carbonate) as the raw material. An attempt to address the problems in the Nation's transportation infrastructure could increase consumption in the construction sector, especially for soil stabilization in major projects such as airport and highway construction and as an antistripping agent in asphalt. Lime consumption for precipitated calcium carbonate (PCC) production will continue to increase dramatically as the push to build satellite PCC plants near paper mills continues. The continued expansion of western gold production will provide a growing market for lime consumed in the cyanide heap-leaching process. Two producers of soda ash in Wyoming have constructed facilities for the lime-soda production of caustic soda, and a third is in the planning stage. This could develop into a significant regional market for lime.

Consumption by the pulp and paper industry increased by 7% in 1990. However, the pulp and paper industry tends to lag the national economy by several months, and the effects of the recession will probably impact them during 1991. Industry forecasts call for an overall growth rate in the industry of 2% to 3% per year.

[1]National Lime Association. Chemical Lime Facts. Bull. 214, 5th ed., 1988, 44 pp.

[2]Boynton, R. S. Chemistry and Technology of Lime and Limestone. John Wiley & Sons, 1980, 578 pp.

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[9]Hanson, D. Chemical Method for Destroying PCB's Found. Chem. & Eng. News, v. 69, No. 11, 1991, pp. 5–6.

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